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Inventory of Technologies, Methods, and Practices

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28.1. Introduction

The inventory is a database containing information on technologies, methods, and practices that can help to limit emissions of greenhouse gases. The inventory contains information on performance characteristics and applications, capital and operating costs, environmental characteristics (including emissions of greenhouse gases), and infrastructure requirements. The information is compiled in a two-page, standardized format for each technology. The inventory contains information on 105 technologies, including energy supply technologies (44), energy end-use technologies (47), agricultural and forestry practices (12), and other techniques (2). Table 28-1 lists all the technologies in the inventory. The inventory is published as an appendix volume to the Second Assessment Report.

The rationale for the inventory is straightforward. As the global climate change debate shifts toward studying the need for action, it is increasingly important for energy and environmental planners to have access to technical and economic information on the options that are available to reduce emissions and mitigate climate change. This information should be current, consistent, reliable, and widely available. In some countries, very good technology data and sophisticated analytical tools already exist. Often, however, information available from national or regional studies cannot be directly compared or adapted to new conditions because it has been collected in different formats or is based on different assumptions. Some countries, particularly developing and newly industrializing countries, lack sufficient resources to explore the benefits of these technologies on their own. In these cases, planners may rely on data of uncertain provenance, which can lead to unbalanced assessments of technology options, questionable data quality, and, ultimately, poorly informed investments. The need for wide access to a standardized data set drove the assembly of this inventory.

The inventory is designed for use by planners and analysts needing to evaluate options for reducing greenhouse gas emissions that are potentially attractive for near- and medium-term applications (say, the next 5–15 years). Some applications for which the inventory would be well suited are:

- Selection of technological options for use in different parts of the world
- National or regional economic development planning
- National or regional studies of greenhouse-gas emission reduction policies
- Macroeconomic analyses of large-scale climate change mitigation policies.

Although the inventory can be of value in prescreening technological options for specific applications, it is *not* intended to support the following types of studies:

- Engineering design or installation studies
- Site-specific applications
- Detailed technology transfer evaluations.

The inventory does not make any recommendations concerning specific types of technological systems or vendors.

Information on experience with advanced technologies in industrialized countries has been supplemented with information on applications of these technologies in developing countries. As the inventory develops, the aim is to increasingly make it a global resource and make its ownership world-wide. In the interim, users may replace inappropriate data elements with country-specific information that meets their local needs. In the longer term, the inventory will be made available to users in a computerized version. The software will provide guidance and data to permit conversion of data elements, especially costs, to local conditions. The inventory will be improved and extended in the future as a result of applications studies, such as the U.S. Country Studies Program, and government reviews of the material presently included. These additional items will include greater regional discrimination of data ranges, efficiencies achieved in recent practice, and comparative indications of development status.

The following section includes three examples illustrating the type of information contained in the inventory. The format of information for each technology in the inventory follows the outline provided in Table 28-2.

28.2. Emission Reduction Technologies

Carbon dioxide is emitted in large quantities by human activities, mostly as a result of combustion of fossil fuels and vegetation. Many techniques have been demonstrated to limit emissions of carbon dioxide from fuel-burning activities by improving the efficiency with which stored energy is converted to useful energy. The inventory characterizes many such approaches that have higher energy supply efficiencies than conventional systems. These approaches cover direct energy production in the industrial sector, as well as electricity generation, transmission, and distribution. Some of the technologies described are particularly suitable for the kinds of fuel resources, energy demands, and infrastructure found in developing countries. Appropriate technologies for developing countries, such as efficient cook stoves, are included in the inventory. Additionally, energy supply technologies that can replace fuel-burning technologies and essentially eliminate the direct production of carbon dioxide are described. Emphasis is placed on renewable energy supplies (biomass, solar, hydro, and wind energy). However, because some industrializing countries are considering nuclear energy as an option to meet electricity demand without adding to carbon dioxide emissions, several advanced nuclear energy options are included.

A range of technologies can improve the efficiency with which energy is consumed in various applications. Energy end-use technologies for buildings, transportation, and industry are included. Many of these technologies can provide substantial improvements in energy efficiency over conventional approaches, and the capital investments often can be recovered

Table 28-1: *List of technologies contained in the inventory.*

A. Energy Supply—Fossil Fuel Technologies
A.1 Atmospheric Fluidized-Bed Combustion (AFBC)
A.2 Coal Beneficiation
A.3 Coal-Water Mixtures
A.4 Combined Cycle
A.5 Combustion Turbines
A.6 Diesel Cogeneration
A.7 Fuel Cells
A.8 Industrial Cogeneration
A.9 Gas/Oil-Fired Steam Units
A.10 Integrated Gasification Combined Cycle (IGCC)
A.11 Inter-cooled Steam Injected Gas Turbine (ISTIG/STIG)
A.12 Pressurized Fluidized-Bed Combustion (PFBC)
A.13 Pulverized Coal-Fired Power Plant
A.14 Slagging Combustors
A.15 Oil and Natural Gas: Reduced Venting and Flaring of Gas during Production
A.16 Oil and Natural Gas: Improved Compressor Operations
A.17 Oil and Natural Gas: Improved Leak Detection and Pipeline Repair
A.18 Oil and Natural Gas: Low-Emission Technologies and Practices
A.19 Coal Mining: Enhanced Gob Well Recovery
A.20 Coal Mining: Pre-Mining Degasification
A.21 Coal Mining: Integrated Recovery

B. Energy Supply—Renewable Energy Technologies
B.1 Biomass-Fired Power Generation
B.2 Flat-Plate Photovoltaics
B.3 Geothermal Electric
B.4 Municipal Solid Waste (MSW) Mass Burn
B.5 Pelletized Biomass Combustion
B.6 Biogas by Anaerobic Digestion
B.7 Small-Scale Hydro
B.8 Solar Ponds
B.9 Solar Thermal Electric-Parabolic Trough
B.10 Solar Thermal Electric-Central Receiver
B.11 Solar Thermal Electric-Parabolic Dish/Stirling Engine
B.12 Wind Energy Conversion Systems
B.13 Tidal Energy
B.14 Ocean Wave Energy
B.15 Landfills: Gas Recovery and Utilization Techniques

C. Energy Supply—Nuclear Technologies
C.1 Light Water Reactors
C.2 Heavy Water Reactors
C.3 Liquid Metal Fast Reactors
C.4 Gas-Cooled Reactors

D. Energy Supply—Energy Transfer Technologies
D.1 Efficient Electrical Transformers
D.2 Electric Transmission and Distribution Systems
D.3 Thermal Energy Storage Systems
D.4 High-Voltage Direct-Current Transmission

E. Energy End-Use—Transportation Technologies
E.1 Advanced Signalization
E.2 Battery Electric Vehicles (EVs)
E.3 Compressed Natural Gas (CNG) Vehicles
E.4 Continuously Variable Transmission (CVT)
E.5 Direct-Injection Diesel Engines
E.6 Efficient Jet Aircraft
E.7 Efficient Tires
E.8 Ethanol Vehicles
E.9 Fuel-Cell Electric Vehicles (FCVs)
E.10 Two-Stroke Spark-Ignition Engines
E.11 Urban Transit Systems

F. Energy End-Use—Buildings Technologies
F.1 Adjustable Speed Electric Motor Drives
F.2 Advanced Insulation: Gas Filled Panels
F.3 Compact Fluorescent Lights
F.4 Electronic Ballasts
F.5 Efficient Electric Motors
F.6 Efficient Refrigerators
F.7 Energy Management Systems (EMS)
F.8 Glazing: Daylight Control
F.9 Glazing: Insulating
F.10 Glazing: Solar Control
F.11 Glazing: Switchable
F.12 Heat Pump Water Heaters
F.13 High-Albedo Materials
F.14 Landscaping
F.15 Lighting Controls
F.16 Room Air Conditioners (Window-Type)
F.17 Solar Domestic Water Heaters
F.18 Efficient Cooking Stoves

G. Energy End-Use—Industrial Technologies
G.1 Anaerobic Biological Treatment of Waste
G.2 Biofiltration of Gases
G.3 Cement Particle High-Efficiency Air Classifiers
G.4 Ceramic Recuperators
G.5 Continuous Pulp Digesters
G.6 Continuous Steel Casters
G.7 Distillation Control Systems
G.8 Electric Motors Variable Speed Drives—Industrial
G.9 Gas Membrane Separators
G.10 Heat Exchanger Enhancement Techniques
G.11 High-Efficiency Welding Power Supply
G.12 Mechanical Dewatering
G.13 Metal Parts Cleaning
G.14 Pinch Technology
G.15 Pipe Cross Reactors
G.16 Plating Waste Concentrators
G.17 Pulse Combustion Boilers
G.18 Textile Dyeing Vacuum System

H. Agricultural and Forestry Practices
H.1 Reduction in Use of Nitrogen Fertilizer and Animal Manure
H.2 Reduction in Tillage of Agricultural Soils
H.3 Reforestation/Afforestation and Prevention of Deforestation
H.4 Increasing Efficiency/Intensity of Forest Management
H.5 Substitution of Fossil Fuels with Sustainably-Grown Fuelwood
H.6 Increasing Agroforestry Endeavors
H.7 Livestock: Improved Nutrition/Mechanical and Chemical Feed Processing
H.8 Livestock: Improved Nutrition/Strategic Supplementation
H.9 Livestock: Production-Enhancing Agents
H.10 Livestock Manure: Covered Lagoons
H.11 Livestock Manure: Small-Scale Digesters
H.12 Livestock Manure: Large-Scale Digesters

I. Other Techniques
I.1 Landfills: Reducing Landfilling of Waste
I.2 Wastewater Treatment

Table 28-2: *Data elements contained in the inventory.*

General Characteristics
Sector
Applications
Typical Size
Design Fuels
Performance Measure
Design Lifetime
Construction Time
Development Status

Cost Information
Source and Year
Capital and Installation Cost
Nonfuel Operating Cost
Fuel Cost

Environmental Characteristics
Waste Streams
Air Emissions
Greenhouse Gas Emissions
Site-Specific Issues
Retrofit Potential

Infrastructure Requirements
Operating Personnel
Maintenance Personnel
Infrastructure Needs

References

rapidly through energy cost savings and lower operating and maintenance costs. Improved products or better energy services often are ancillary benefits. In many cases, the technologies are easily transferred to developing countries and simple to install and use. The reduction in greenhouse gas emissions that can be gained through the use of higher efficiency end-use technologies depends on the type of fuel used to produce the displaced energy and the efficiency of the primary energy conversion process.

Although research is underway on a variety of techniques for capturing carbon dioxide once it has been produced and then utilizing it or disposing of it, such systems are not included in this inventory because they are not likely to be of significant commercial potential in the near- to medium-term time frame of this inventory.

Methane is emitted from a diverse set of human-related activities that currently represent about 70% of global emissions. Importantly, methane emissions from these activities represent the waste of a valuable fuel; the methane often can be recovered under conditions where the saved fuel justifies the investment. Sixteen currently available technologies and practices are identified and characterized in the inventory. These technologies and practices have been demonstrated to use otherwise wasted methane profitably, have been implemented to some extent already, and could be implemented on a much more widespread basis. They are economically viable under a range of conditions, represent different levels of technical complexity and capital needs, and should be adaptable to a wide variety of country conditions. Furthermore, these technologies and practices are generally attractive options because of the many other benefits that they provide—benefits that are consistent with the development goals of many countries.

The inventory contains characterizations for a range of major methane sources that spans energy and agricultural activities covering about 70% of anthropogenic emissions: natural gas systems, coal mining, waste disposal, wastewater treatment, and domesticated livestock. Efforts still are required to develop and demonstrate options for reducing methane emissions from rice cultivation and biomass burning, and therefore these methane sources are not reflected in the inventory at present. The latest research efforts in these areas have been documented by the U.S./Japan Working Group on Methane (1992).

28.2.1. Example 1: Energy Supply—Fossil Fuel Technologies

Pressurized Fluidized-Bed Combustion

Pressurized fluidized-bed combustion (PFBC) is an advanced technology for burning coal that offers high thermal efficiency and low environmental emissions. The system operates at pressures of 6–16 atmospheres and typically utilizes smaller combustion chambers than a conventional furnace because of its more efficient steam production. Due to its high thermal efficiency, PFBC can reduce the quantity of carbon dioxide emitted per unit of energy produced. Therefore, it is a potentially useful technology for mitigating emissions generated in the production of electricity. The inventory identifies the anticipated size of commercial PFBC units (200–400 MW_e), their application (electric power generation), and the fuels that can be used. Performance measures of the technology are provided in terms of the operating thermal efficiency of current demonstration plants (33–42%) and of projected second-generation plants (45–50%).

The capital cost of current demonstration plants ($1900–$3200/kW) is compared with the expected costs of a mature, commercial unit (about $1500/kW) and a second-generation plant (about $1000/kW). Nonfuel operating and maintenance costs range between 2.0 and 2.5¢/kWh. Fuel costs can range anywhere between 2.2 and 34¢/kWh, depending on the type of fuel chosen. The environmental performance of PFBC is very good; it generates relatively small quantities of solid waste, which can be safely landfilled or sold as a byproduct, and it produces low emissions of sulfur dioxide and nitrogen oxides. Most importantly for global climate change, emissions of carbon dioxide are estimated to be in the range of 930–1060 g CO_2/kWh, lower than conventional pulverized coal plants. Labor requirements to operate a PFBC plant (25–89, depending on size) and to maintain it (40–60) are presented, together with relevant information on infrastructure requirements, such as the need for connection to an electricity transmission grid.

28.2.2. Example 2: Energy End-Use Technologies

Compact Fluorescent Lights

Compact fluorescent lights are three to four times more energy efficient than incandescent bulbs and last ten times as long. They can therefore reduce the amount of electricity required to deliver a given amount of lighting. The reduction in carbon dioxide emissions will depend on the fuel used to generate the electricity. Compact fluorescent units are available with screw-in adaptors for use in incandescent lamp fixtures or as dedicated fixtures. Compact fluorescents also are available as integrated lamp/ballast/adapter units; however, since the ballasts typically outlive the lamps, integration of ballast and lamp results in the ballast being discarded before the end of its useful life. Lower wattage twin tubes cost about $5 per lamp. The more luminous quad tubes cost about $9 per lamp. Integrated units cost about $15–25 per lamp. Utility rebates in the range of $4–15 per lamp typically are available in the U.S.

Compact fluorescent lights are slightly bigger and heavier than incandescent bulbs. Thus, they may not be a suitable replacement in every application. Performance suffers in tight fixtures, and under-lit spaces may result if thermal effects are not considered in system planning. Preheat lamps have a 1- to 2-second delay before lighting, although rapid-start systems are becoming available.

28.2.3. Example 3: Energy Supply—Renewable Energy Technologies

Landfills: Gas Recovery and Utilization Techniques

Recovering gas from landfills reduces methane emissions and allows the energy value of the recovered methane to be used profitably. The recovery technologies are relatively straightforward: Gas wells are drilled into an area of disposed waste, and collection systems are installed. These systems typically recover 50–85% of the gas generated. The recovered gas is about 50% methane, a medium-Btu fuel. It typically requires some processing to remove particulate matter, water, and corrosive compounds. The costs of the technology depend on the costs for recovery systems, labor, and utilization systems. Landfill gas recovery provides additional benefits in the form of reduced explosion hazard and protection of local air and water quality. The best opportunities are for large waste-disposal sites that have a nearby demand for medium-quality fuel.

28.3. Other Technology Inventories

Several other initiatives are under way aimed at gathering and disseminating information on technologies for limiting greenhouse gas emissions or increasing greenhouse gas uptake. Efforts will be made to coordinate this inventory with these other systems.

The Environmentally Compatible Energy Strategies (ECS) Project at the International Institute for Applied Systems Analysis in Laxenburg, Austria, has developed a comprehensive inventory of technological options for mitigating and adapting to possible global warming (Schafer *et al*., 1992). The supporting data base, CO2DB, contains detailed descriptions of the technical, economic, and environmental performance of approximately four hundred technologies. Efficiency improvements, conservation, enhanced use of low-carbon fuels, carbon-free sources of energy, afforestation, and enhancement of carbon sinks are included.

At the Forschungszentrum Julich GmbH in Germany, the IKARUS Project has been involved in the development of computer models and a database for comparing strategies for reducing the energy-related emissions of greenhouse gases, particularly carbon dioxide (Katscher, 1993). The technology database in the IKARUS system contains basic technical, economic, and environmental data on individual technologies that can be used to construct technology chains and feed to sector-specific simulation models. The goal is to be able to assess mitigation possibilities for the German energy system in 1989, 2005, and 2020.

The International Energy Agency (IEA) has two related activities. The IEA established the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), an Implementing Agreement that offers an international network to exchange information on demonstrations of energy-saving end-use technologies for all energy consumers (IEA, 1991). CADDET maintains *The CADDET Register,* a computerized database providing information on international energy demonstration projects. Also, the IEA has implemented the Energy Technology Systems Analysis Programme (ETSAP), an Implementing Agreement that also distributes technology information to IEA member countries (IEA, 1992).

An interagency joint project on databases and methodologies for comparative assessment of different energy sources for electricity generation (DECADES) has been established by the International Atomic Energy Agency (IAEA), in collaboration with several other international organizations, with the objective of enhancing capabilities for incorporating health and environmental issues in the comparative assessment of different electricity generation chains and strategies (IAEA, 1995). The DECADES project includes a technology inventory that characterizes energy chains for electricity generation from fuel extraction to waste management, as well as an information system that provides user-oriented access to electronic databases.

28.4. Obtaining a Copy of the Inventory

Copies of the inventory may be obtained by contacting the Convening Lead Author or through the U.S. Country Studies

Program. The Convening Lead Author may be contacted at the following address:

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Decision and Information Sciences Division, DIS/900
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International Energy Agency, 1991: *CADDET Brochure*. Centre for the Analysis and Dissemination of Demonstrated Energy Technologies, Organization for Economic Cooperation and Development, Paris, France.

International Energy Agency, 1992: *IEA/ETSAP News*. Energy Technology Systems Analysis Programme, Annex IV: Greenhouse Gases and National Energy Options, The Netherlands Energy Research Foundation, Petten, The Netherlands.

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Schafer, A., L. Schrattenholzer, and S. Messner, 1992: *Inventory of Greenhouse-Gas Mitigation Measures: Examples from the IIASA Technology Data Bank*. Working Paper WP-92-85, International Institute for Applied Systems Analysis, Laxenburg, Austria, 66 pp.

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